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Review

Potentials of Endophytic Fungi in the Biosynthesis of Versatile Secondary Metabolites and Enzymes

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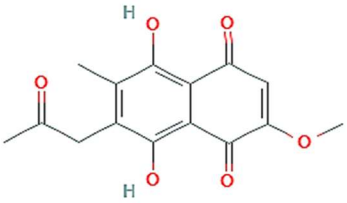
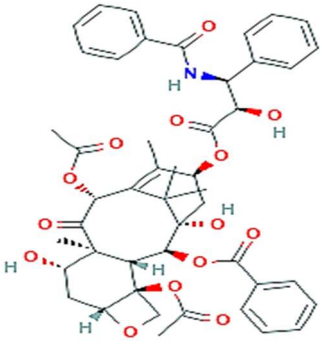
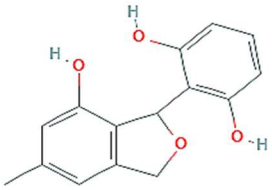
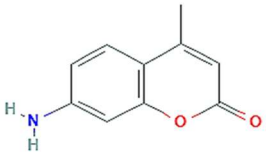
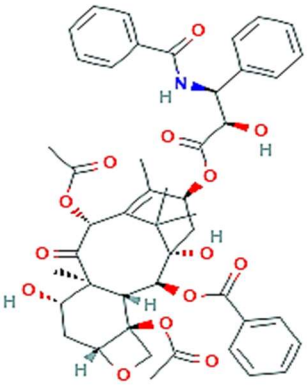
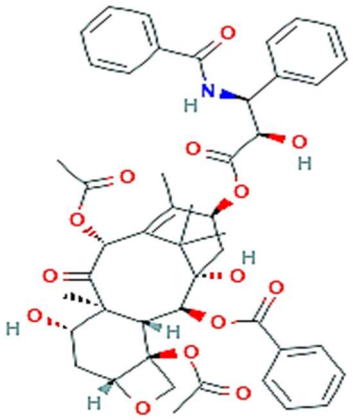
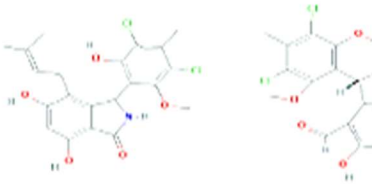
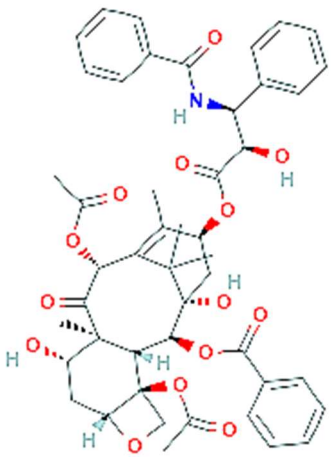
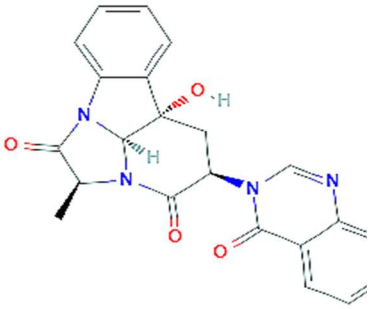
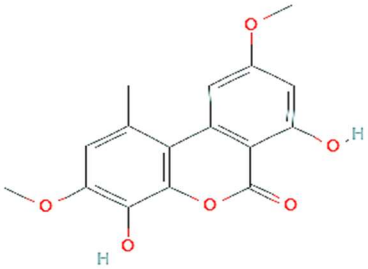
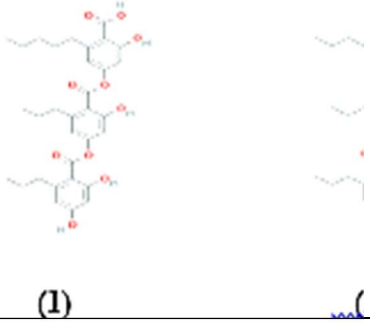
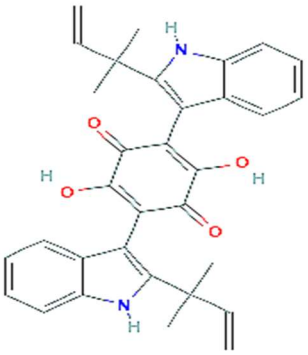
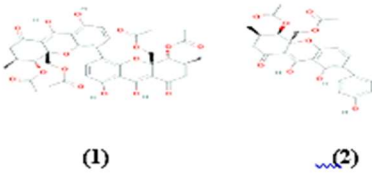
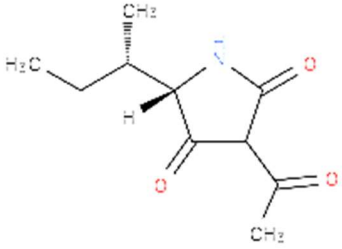
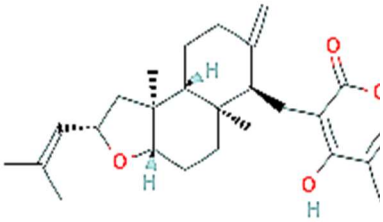
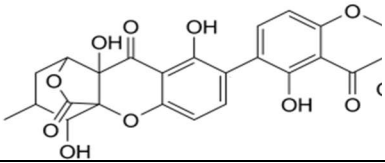
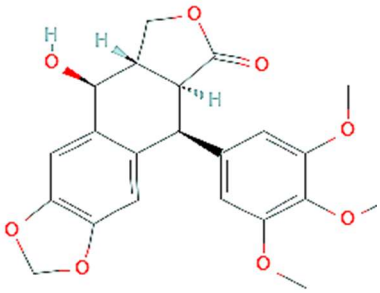
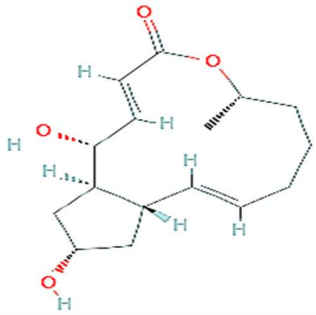
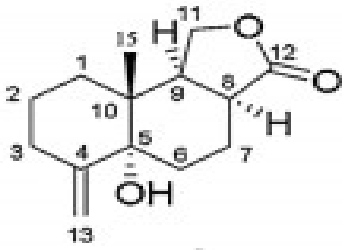
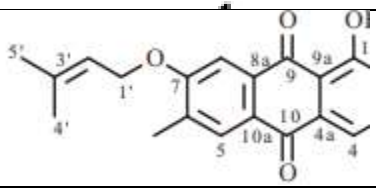
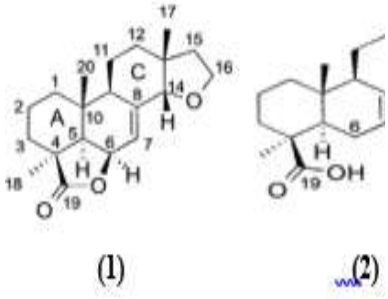
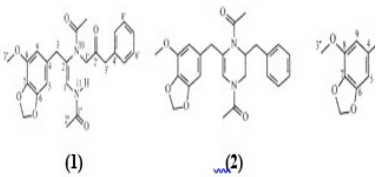
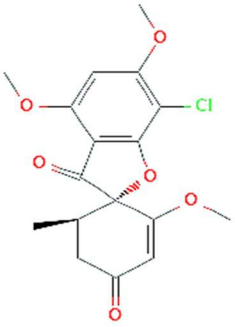
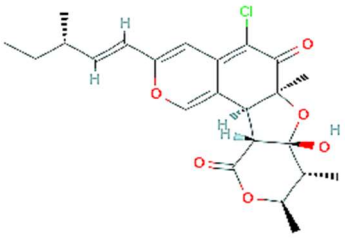
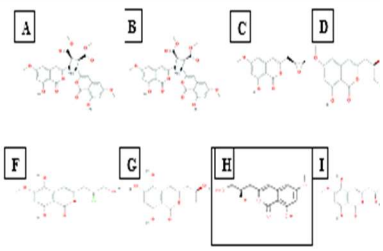
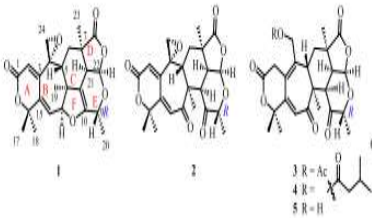
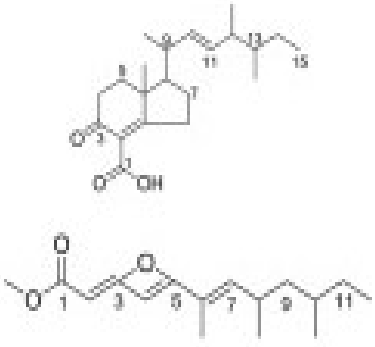
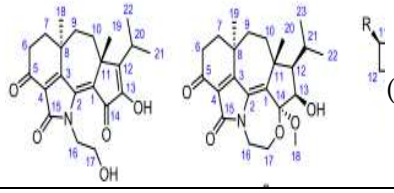
Table S1. Medicinal applications of novel secondary metabolites produced by endophytic fungi.

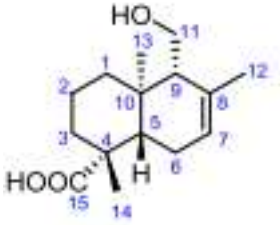
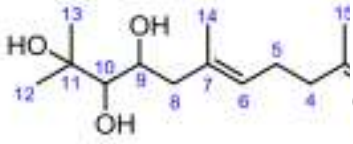
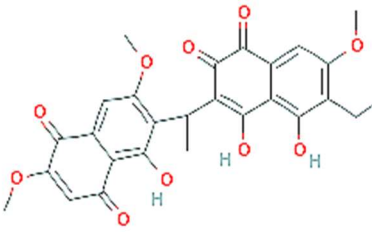
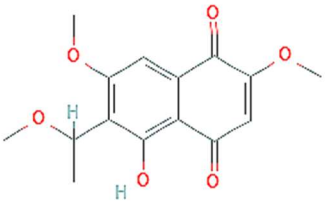
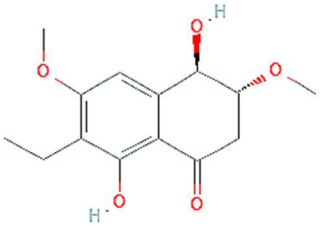
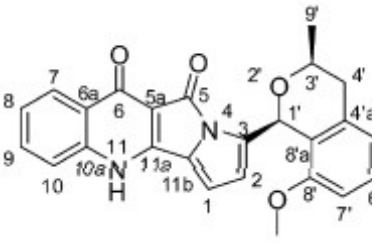
Compounds	Fungal endophytes	Host plants	Biological activities	Structural formulas	References
Javanicin	*Chloridium* sp.	*Azadirachta indica*	Antibacterial activity		(Kharwar et al., 2009)
Taxol	*Tubercularia* sp. TF5	*Taxus mairei*	Anticancer activity		(Wang et al., 2000)
Pestacin	*Pestalotiopsis microspora*	-	Antioxidant and antimycotic activities		(Harper et al., 2003)
7-amino-4-methylcoumarin	*Xylaria* sp.YX-28	*Ginkgo biloba*	Antimicrobial activity		(Liu et al., 2008)
Camptothecin	-	*Camptotheca acuminata*	Antineoplastic agent		(Kusari et al., 2009)

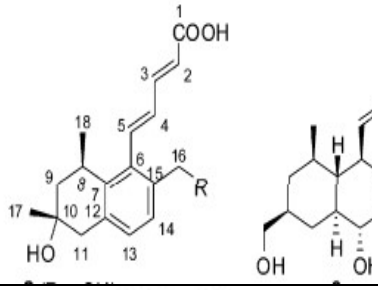
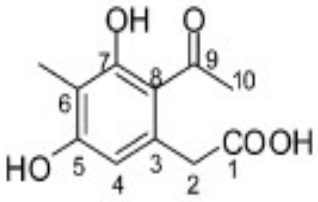
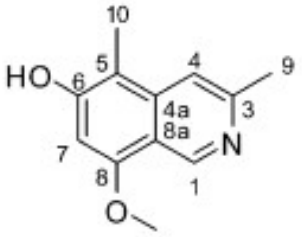
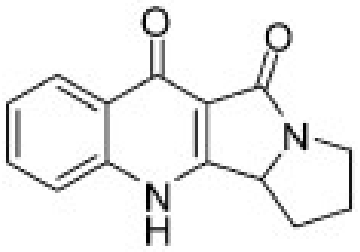
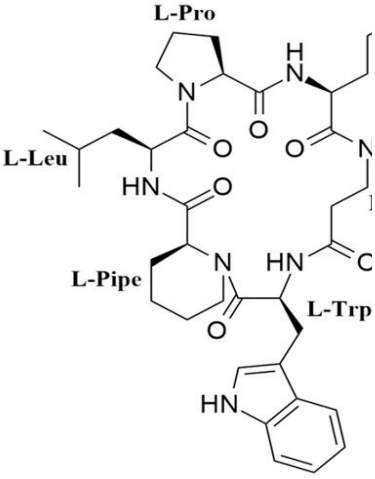
Taxol	*Fusarium solani*, Tax-3	*Taxus chinensis*	Anticancerous activity		(Deng et al., 2009)
Pestalachlorides A–C (1-2)	*Pestalotiopsis adusta*	-	Antifungal activity	 (1) (2)	(Li et al., 2008)
Taxol	*Taxomyces andreanae*	*Taxus brevifolia*	Anticancerous activity		(Stierle et al., 1993)
Chaetominine	*Chaetomium* sp. IFB-E015	*Adenophora axilliflora*	Cytotoxic activity		(Jiao et al., 2006)
Graphislactone A	*Cephalosporium* sp. IFB-E001	*Trachelospermum jasminoides*	Antioxidant activities		(Song et al., 2005)

Cytonic Acids A (1) and B (2)	*Cytonaema* sp.	-	Tridepside Inhibitors of hCMV Protease	 (1) (	(Guo et al., 2000)
Hinnuliquinone	-	-	Inhibit HIV-1		(Singh et al., 2004)
Phomoxanthones A and B	*Phomopsis* sp. BCC 1323	-	Antimalarial and antitubercular activities and cytotoxicity	 (1) (2)	(Isaka et al., 2001)
Tenuazonic Acid	*Alternaria alternata*	-	Antibacterial activity against *Mycobacterium tuberculosis* H37Rv		(Sonaimuthu et al., 2011)
Subglutinol A	*Fusarium subglutinans*	*Tripterygium wilfordii*	Immunosuppressive activity		(Lin et al., 2014)
Ergoflavin	-	*Mimosops elengi*	Anti-Inflammatory and Anticancer Activity		(Deshmukh et al., 2009)

Podophyllotoxin	-	*Podophyllum peltatum*	Anticancer agent		(Ardalani et al., 2017)
Brefeldin A	*Penicillium* sp. FKI-7127	-	Antiviral activity		(Raekiansyah et al., 2017)
14-nordrimane	*Phoma* sp.	*Aconitum vilmorinianum*.	Antiviral activity		(Liu et al., 2019)
Anthraquinone, 7-(γ,γ)-dimethylallyloxy macrosporin	*Phoma* sp. L28.	Mangrove	Antifungal activity		(Huang et al., 2017)
Xylabisboein A and B	*Xylaria* sp. SNB-GTC2501	*Bisboecklera microcephala*	Antibacterial activity	 (1) (2)	(Sorres et al., 2015)
Brasilamides A (1), B (2) and F (3)	*Penicillium brasilianum*	*Melia azedarach*	Anticancer activity	 (1) (2)	(Fill et al., 2010)

Griseofulvin	*Xylaria* sp.F0010	*Abies* sp.	Antifungal activity		(PARK et al., 2005)
Chaetomugilin D	*Chaetomium globosum*	*Ginkgo biloba*	Antimicrobial activity		(Qin et al., 2009)
Peniisocoumarins A–J	*Penicillium commune* QQF-3	*Kandelia candel*	Cytotoxicity and enzyme inhibitory activities		(Cai et al., 2018)
Amestolkolides A-D	*Talaromyces amestolkiae* YX1	Mangrove	Anti-inflammatory		(Chen et al., 2018)
Fusariumins C and D	*Fusarium oxysporum* ZZP-R1	*Rumex madaio*	Antimicrobial activities		(Chen et al., 2019a)
Koninginols A-C	*Trichoderma koningiopsis* A729	*Morinda officinalis*	Antitumor activity		(Chen et al., 2019b)

11-hydroxy-15-drimeneoic acid	*Trichoderma koningi opsis* A729	*Morinda officinalis*	Antitumor activity		(Chen et al., 2019b)
Koninginol D	*Trichoderma koningi opsis* A729	*Morinda officinalis*	Antitumor activity		(Chen et al., 2019b)
Neofusnaphthoquinone A	*Neofusicoccum austral* SYSU-SKS024	Mangrove	Indoleamine 2, 3-dioxygenase (IDO) inhibitory activity		(Cui et al., 2018)
6-(1-methoxylethy1)-2,7-dimethoxyjuglone	*Neofusicoccum austral* SYSU-SKS024	Mangrove	Indoleamine 2, 3-dioxygenase (IDO) inhibitory activity		(Cui et al., 2018)
(3R,4R)-3-methoxyl-botryosphaerone D	*Neofusicoccum austral* SYSU-SKS024	Mangrove	Indoleamine 2, 3-dioxygenase (IDO) inhibitory activity		(Cui et al., 2018)
Citriquinochroman	*Penicillium citrinum*	*Ceratonia siliqua*	Cytotoxic activity		(El-Neketi et al., 2013)

Tanzawaic acids G and H	*Penicillium citrinum*	*Ceratonia siliqua*	-		(El-Neketi et al., 2013)
6-methylcurvulinic acid	*Penicillium citrinum*	*Ceratonia siliqua*	-		(El-Neketi et al., 2013)
8-methoxy-3,5-dimethylisoquinolin-6-ol	*Penicillium citrinum*	*Ceratonia siliqua*	-		(El-Neketi et al., 2013)
1,2,3,11b-tetrahydroquinolactacide	*Penicillium citrinum*	*Ceratonia siliqua*	-		(El-Neketi et al., 2013)
Pipecolisporin	*Nigrospora oryzae*	*Triticum aestivum*	Antimalarial and Antitrypanosome activities		(Fernández-Pastor et al., 2021)

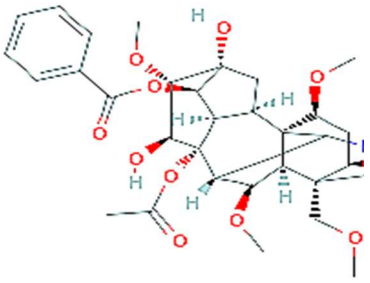
Aconitine	*Cladosporium cladosporioides*	*Aconitum leuco stomum*	Cardiotoxic, anticancer, anti-neuralgic and anti-inflammatory		(Yang et al., 2013)

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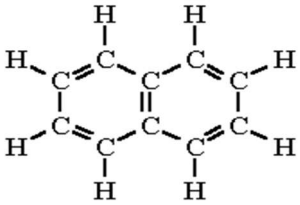
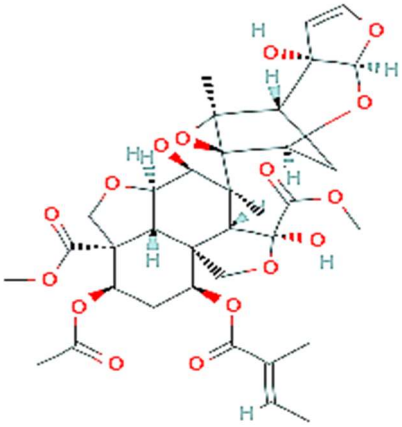
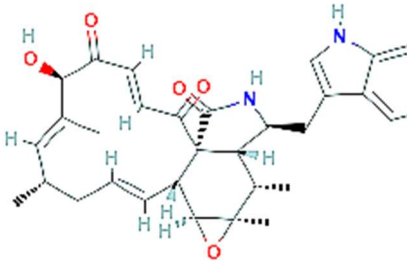
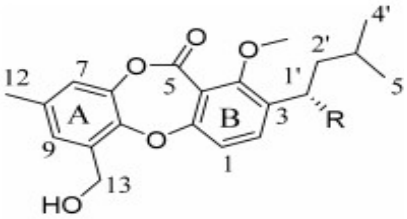
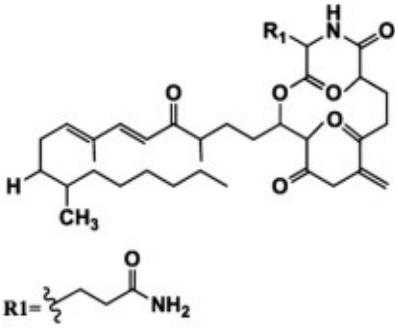
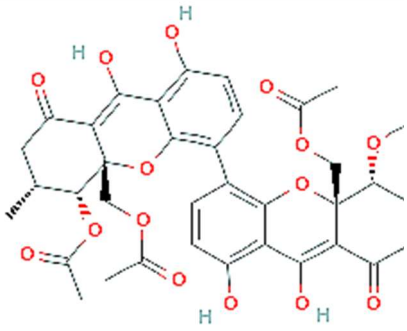
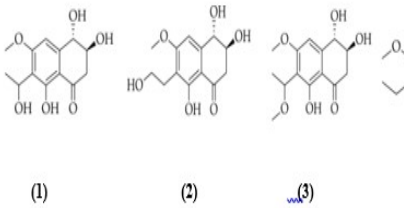
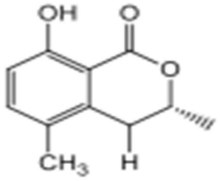
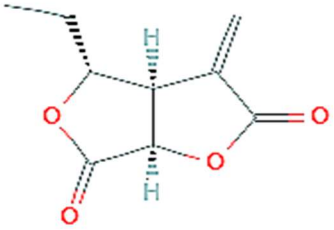
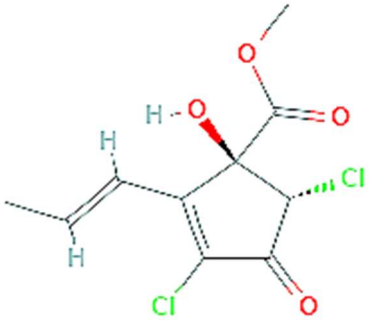
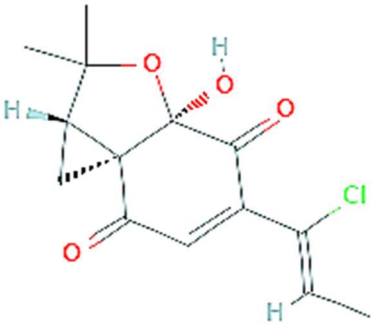
Table S2. Agricultural applications of novel secondary metabolites produced by endophytic fungi.

Compounds	Fungal endophytes	Host plants	Biological activities	Structural formulas	References
Naphtalene	*Muscodor vitigenus*	*Paullinia paullinioides*	Insect repellent activity		(Daisy et al., 2002)
Azadirachtin	*Azadirachta indica*	-	Insecticidial activity		(Verma et al., 2014)
Chaetoglobosin A	*Chaetomium* spp.	-	Antifungal activity		(Ortega et al., 2020)
Talaromyones A (1) and B (2)	*Talaromyces stipitatus* SK-4)	*Acanthus ilicifolius*	Antibacterial activity	 **1**: R = OH **2**: R = OAc	(Cai et al., 2017)
Fusaristin A	*Phomopsis* sp.	-	Antimicrobial activity		(Lim et al., 2010)

Phomoxanthone A	*Phomopsis* sp	*Costus* sp	Antimicrobial activity		(Elsässer et al., 2005)
Botryosphaerones A-D (1-4)	*Botryosphaeria australis*	*Sonneratia apetala*	Cytotoxic and antimicrobial activities	 (1) (2) (3)	(Xu et al., 2011)
5-Methylmellein	*Xylaria* sp. PSUG12	*Garcinia hombroniana*	Insecticidal activity		(Rukachaisirikul et al., 2013)
4-epi-ethiosolide	*Pezicula* sp.	Coniferous tree	Fungicidal and herbicidalactivities		(Schulz et al., 1995)
(+)-cryptosporiopsin	*Pezicula* sp.	Coniferous tree	Fungicidal and herbicidalactivities		(Schulz et al., 1995)
(-)-mycorrhizin A	*Pezicula* sp.	Coniferous tree	Fungicidal and herbicidalactivities		(Schulz et al., 1995)

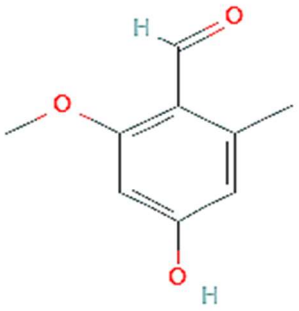
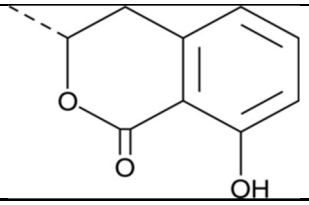
4-Hydroxy-2-methoxy-6-methylbenzaldehyde	*Pezicula* sp.	Coniferous tree	Fungicidal and herbicidalactivities		(Schulz et al., 1995)
(R)-mellein	*Pezicula* sp.	Coniferous tree	Fungicidal and herbicidalactivities		(Schulz et al., 1995)

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Table S3. Industrial applications of extracellular enzymes produced by endophytic fungi.

Compounds	Fungal endophytes	Host plants	Biological activities	References
Amylase	*Streptosporangium* sp.	*Zea mays*	Starch hydrolysis	(Stamford et al., 2002)
Amylase	*Cylindrocephalum* sp.	*Alpinia calcarata*	Starch hydrolysis	(Sunitha. et al., 2012)
Lipase	*Fusarium oxysporum*	*Croton oblongifolius*	Catalyze a wide range of chemical reactions in aqueous and non-aqueous environments	(Panuthai et al., 2012)
Protease	*Fusarium* sp. CPCC 480097	*Chrysanthemum*	Proteins degradation	(Wu et al., 2009)
Lipase	*Cercospora kikuchii*	-	Catalyze the hydrolysis of triacylglycerols to fatty acids, mono- and diacylglycerols, and glycerol	(Costa-Silva et al., 2011)
Cellulase	*Xylaria* sp.	*Opuntia ficus-indica*	Hydrolysis of cellulose	(Bezerra et al., 2012)
Pectinase	*Penicillium glandicola*	*Opuntia ficus-indica*	Hydrolysis of pectine	(Bezerra et al., 2012)
Cellulase	*Penicillium* sp.	*Centella asiatica*	Cellulose degradation	(Devi et al., 2012)
Cellulase	*Fusarium oxysporum*	*Baccharis dracunculifolia*	Catalyze cellulolysis	(Onofre et al., 2013)
Amylase	*Aspergillus*	-	Starch hydrolysis	(Khan et al., 2017)
Xylanase	*Alternaria alternata*	*Croton oblongifolius*	Degrade β-1, 4-xylan	(Wipusaree et al., 2011)
Xylanase	*Aspergillus terreus*	*Memora peregrine*	Degrade β-1, 4-xylan	(Sorgatto et al., 2012)
Lipase	*Cercospora kikuchii*	Tithonia diversifolia	Catalyze the hydrolysis of triacylglycerols	(Costa-Silva et al., 2011)
Lipase	*Fusarium oxysporum*	*Croton oblongifolius*	Catalyze the hydrolysis of triacylglycerols	(Amirita et al., 2012)
Pectinase	*Penicillium chrysogenum*	*Asclepias sinaica*	Hydrolyze pectin substances	(Fouda et al., 2015)
Pectinase	*Piriformospora indica*	-	Hydrolyze pectin substances	(Heidarizadeh et al., 2018)
Phytase	*Azospirillum* spp.	*Oryza sativa*	Phytates degradation	(Mehdipour-Moghaddam et al., 2010)
Protease	*Alternaria alternata*	-	Proteins degradation	(Rajput et al., 2016)
Chitinase	*Streptomyces griseus*	*Citrus reticulata*	Chitin hydrolysis	(Quecine et al., 2008)

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